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An Injection Laser-Pumped-Dye-Laser Tunable in the Infrared

LEWIS M. FRAAS*

Universidade Estadual de Campinas, Instituto de Física Gleb Wataghin, Campinas SP

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Extrapolation of data for transverse ruby laser pumped 3,3'-diethylthiotricarbocyanine bromide indicates that this dye will lase with diode injection laser pumping with a threshold of 25 to 30 kW/cm² and an efficiency near 20%. Such a diode pumped dye laser could be quite useful as a broad band amplifier in a laser communication system.

A extrapolação de dados em brometo de 3,3'-dietiltio-tricarbocianina bombeado por um *laser* transversal de rubi indica que esse devera funcionar como *laser,* com bombeamento por *laser* de injeção por diodo com um limiar de 25 a 30 kW/cm² e eficiência de cerca de 20%. Tal dye-laser por bombeamento de diodo poderia ser particularmente útil como um amplificador de faixa larga em um sistema de comunicação por *laser.*

Introduction

Laser light is, unfortunately, usually a rather expensive and inefficient source of radiation. However, a few efficient and sometimes rather inexpensive laser systems do exist. Two quite efficient lasers are the CO, laser and the injection diode laser. When made in large quantities, the injection diode laser is quite inexpensive. Two additional lasers, the Nd laser and the dye laser, are potentially quite efficient but are limited by efficiencies of optical pumping lamps. Fortunately, both the Nd laser and the dye laser can potentially be optically pumped by the diode laser. As efficient laser systems are desirable, it is interesting to explore diode laser pumping of dye lasers. This is even more so as diode lasers, besides being inexpensive, have lifetimes many times longer than laser flash lamp lifetimes.

Although an injection diode array has been used to pump a Nd laser[1], an injection laser array has never been used to pump a dye laser system. This is rather surprising as the dye laser system and the injection laser system are quite compatible. Both the injection laser and the dye laser

*Postal address: Hughes Research Labs., 29229 Heather Cliff Road, N.° 6, Malibu, California 90265.

operate best in the pulsed mode. Both lasers have high quantum efficiencies and both are potentially compact.

In this paper, a feasibility discussion is first given in which it is shown that a diode laser pumped dye laser is quite conceivable. Then a more general discussion is given in which a possible application of such a laser system is described.

In the feasibility discussion section, it is pointed out that the published literature data for one dye, 3,3′-diethylthiotricarbocyanine bromide (DTTC bromide), for the case of ruby laser pumping, can be easily extended to the case of diode laser pumping. Such an extension allows a prediction of threshold pumping power density and overall system efficiency. These predictions indicate that a very practical laser system will result.

In the applications section, the use of a diode laser pumped dye laser system as an amplifier in a diode laser communication link is described. This application illustrates some of the potential advantages of such a system.

Feasibility

The purpose of this section is not to present a theory of dye laser pumping, but simply to point out that a ruby laser has been used to pump a dye, DTTC bromide, and that a diode array can provide an alternative source for that dye. It is shown that a diode array can provide an equivalent pumping power density. We adopt the point of view that, having shown that one dye can be made to lase, extended experimental studies of various dyes are in order.

Now, in relation to the work of Shafer *et al.*[2] on ruby laser pumped DTTC bromide, there are two problems: 1) Can a diode array provide the necessary power densities over a sufficient active length? and 2) Can the diode array output wavelength be coupled to the dye absorption peak?

First, we consider the substitution of the ruby laser pump beam by an equivalent pump beam from a diode laser array. Figure 1 shows a suggested configuration for the laser pumped dye laser. The elliptical cavity allows focusing the full injection laser output power density into the dye laser solution. The pumping is transverse. A 1 cm long monolithic linear array of LOC structure diodes serves best as the diode array (The 1 cm length is chosen because a 1 cm dye cell was used in the ruby laser pump

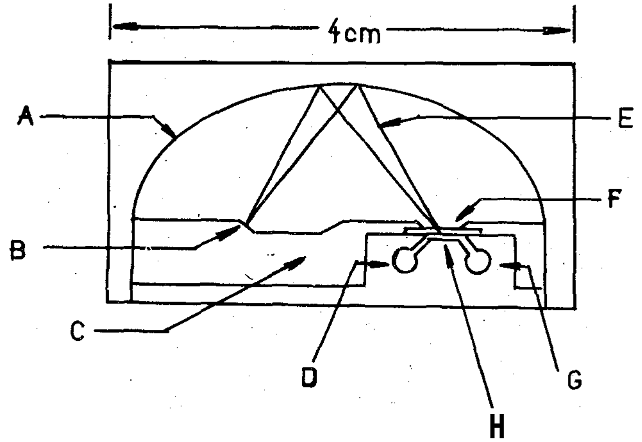

Fig. 1 - This diagram shows a possible configuration for the injection laser pumped dye **laser.**
The arrows indicate **the** following items:

A) Elliptical Reflector	**E) Array Pump Beam**
B) Injection Laser Array	**F) Glass Slide**
C) Copper Heat Sink	**G) Dye Output**
D) Dye Input	**H) Active Region of Dye**

work.). In order to provide a nearly uniform line of high intensity output, the strips of high resistivity material serving to prevent diode lasing along the array length can be made by proton bombardment[3]. Proton bombardment could provide, for example, a 5μ interruption strip after each 100μ wide diode in the array.

The dye solution circulation in figure 1 serves the double function of dye exchange and, if necessary, diode laser heat sink cooling. To facillitate comparison with the literature data for ruby laser pumping, the dye solution cavity lenght of 1 cm is chosen. The dye solution is 10^{-3} molar DTTC bromide in methanol, again as in the ruby laser case.

Second, we consider the problem of pump frequency coupling to the dye absorption band. The solid line in figure 2a shows the absorption spectra as reported by Sorokin et *al.*[4] for DTTC iodide in methanol. The dashed line shown in figure 2a gives a derived absorption spectra for DTTC bromide. The dashed line spectra is derived by shifting the absorption spectra for DTTC iodide in acordance with the 120 Å red shift reported for DTTC bromide by Stepanov et *al.*[5]. From the data of figure 2a, it is clear that the ruby laser frequency at 6934 Å does not fall on the absorption

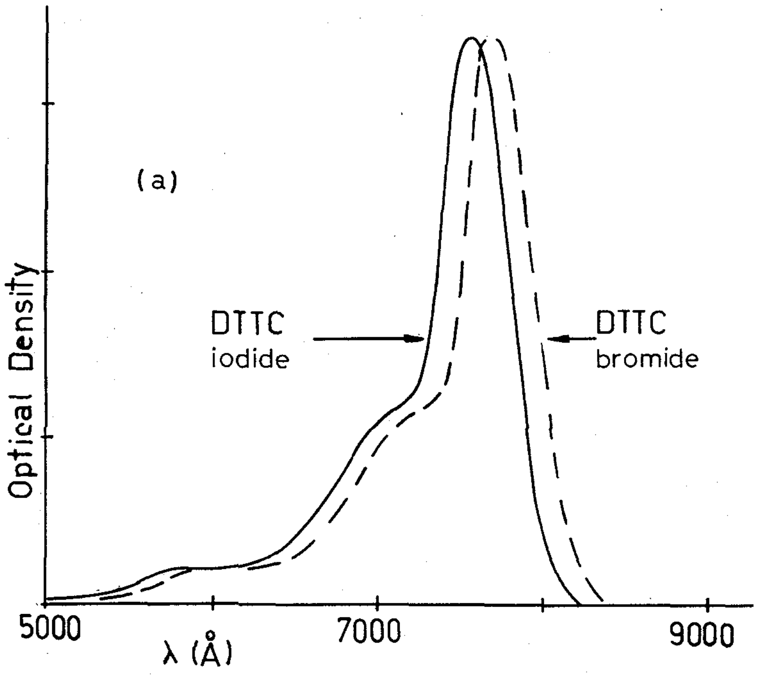

Fig. 2a - The solid (dashed) line shows the absorption spectra for DTTC iodide (bromide) in methanol solution.

peak of either DTTC iodide or bromide. Ripper *et al.*[6] report $Ga_{1-x}Al_x$ As diode laser action over the range from 7450 Å to 8500 Å. Using a diode laser array with a composition such that the lasing frequency falls at 7700 Å, the array can be optimally coupled to the absorption peak of DTTC bromide as shown in figure *2a* Such coupling should be from 3 to 4 times more efficient than that of a ruby laser.

The solid line of figure 2b shows published laser performance data for ruby laser pumped DTTC bromide as reported by Shafer *et al.*[2]. These data show a dye laser threshold at 100 kW/cm^2 transverse pumping power. The dashed lines of figure 2b show extrapolated dye laser performance data for 3 and 4 times more efficient pump frequency coupling. The data of figure 2b show a threshold at 25 to 30 kW/cm^2 for injection laser array pumping. Furthermore, for an array pump power density of 100 kW/cm^2, the predicted dye laser efficiency is 18 %.

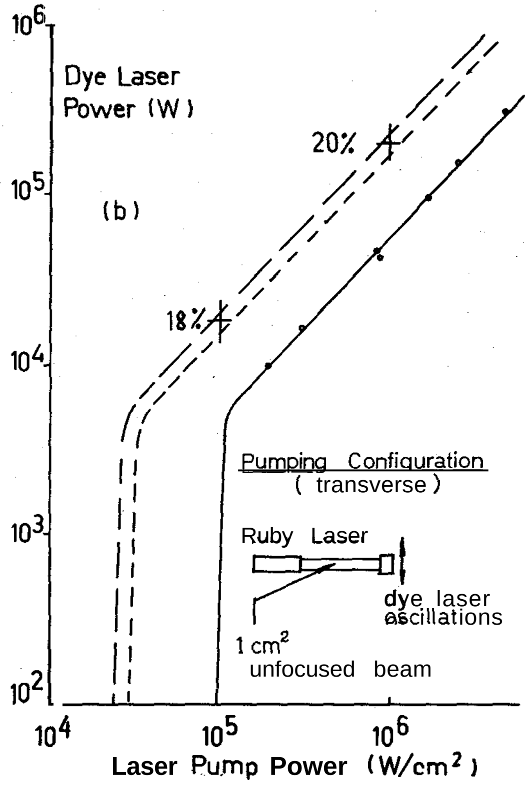

Fig. 2b - The solid (dashed) line shows dye laser peak power vs ruby (diode) laser pump power of a 10^{-3} M solution of DTTC brornide in methanol. Also shown is the ruby laser pump configuration of the ploted data points.

Kressel[7], in a review article on GaAs diode lasers, indicates that peak power densities from 1 to 2 MW/cm^2 are available. He also indicates that such lasers can operate at room temperature at efficiencies up to 10%. Certainly, then a laser power density of 100 kW/cm^2 can easily be obtained for the array in figure 1. Thus, an overall system efficiency of 2% is predicted.

Finally, then, we have shown that DTTC bromide should lase with diode laser pumping. We have not touched on stability, but certainly, many dye candidates exist[8], some of which are quite stable[9,10].

Applications

The system outlined here could be quite useful as a laser surgical scalpel or in pollution control[11]. The laser is small, reasonably efficient, offers low beam divergence, and as is the case for ruby laser pumping, the output is frequency tunable in the IR over the range from 8100 Å to 8600 Å (Ref. 2).

The broad frequency tunability of dyes makes a dye useful, not only as an oscillator (laser) as discussed above, but also as a broad band amplifier. In a communication system, such an amplifier can be useful. It is conceivable that the dye active cross sectional area con be scaled up by scaling up the pump power via a stack of diode laser arrays. Such a stack could be mounted around the circumference of a cylinder, each array pointed at the center. The cylinder diameter should be chosen small enough to allow for the large diffraction limited divergence associated with the diode laser. In a laser system, scaling up the active cross sectional area allows a smaller diffraction limited beam divergence. This is an effectively higher antenna gain. Although a diode laser can be lens converted to the same beam diameter and divergence, this expansion will lower the output power density well below 1 MW/cm^2. With a dye amplifier, a diffraction limited beam of diameter 1 mm with a power density of 1 MW/cm^2 is conceivable. Such power can be obtained with high efficiency via diode laser pumping of a dye amplifier.

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